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Research Paper

Transaction cost analysis of digital innovation governance in the UK energy market

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ABSTRACT

Energy markets are undergoing significant changes. Legacy systems developed around inflexible, centralized and monodirectional supplies are being replaced by flexible, distributed and bidirectional supply-and-demand systems. Where legacy systems are less entrenched, such as in decentralized renewable energy, flexibility and energy service markets, the pace of change is faster, and new technologies, business models and ideas are more likely to be tested and applied. This conceptual paper analyzes the changing governance of decentralized renewable energy, flexibility and energy services in the United Kingdom from a transaction cost perspective. Particular emphasis is placed on the impact of potentially disruptive innovations such as distributed ledgers, emerging digital technologies and big data analytics on the one hand, and the need for value creation from just and affordable decarbonization on the other. In doing so, this paper sheds light on some contradictions between current energy governance and the requirements for a decarbonized, decentralized, digitalized and democratized energy system. The paper concludes that energy governance is increasingly shaped by decentralization and digitalization, which can either facilitate or inhibit value creation through democratization (social value) and decarbonization (environmental value).

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1 INTRODUCTION

According to the World Energy Council (2017a), global energy systems are being transformed by the three reinforcing trends of decarbonization, decentralization and digitalization. This paper also includes democratization in its analysis because transformative trends might have negative consequences relating to equity, accessibility and affordability if value creation is monopolized by rent-seeking organizations. Energy system transformation is thus encapsulated by the so-called 4Ds (Hoggett 2018): decarbonization, decentralization, digitization and democratization. This paper focuses on the energy governance implications of the 4Ds with a particular focus on digital innovations.

Energy governance combines energy law, regulation and policy, which enable or constrain innovation (Kuzemko *et al* 2016; Lockwood *et al* 2017). In the United Kingdom, energy governance arguably tends toward path dependencies and technological lock-ins, which is particularly evident in the continued support for nuclear power (Johnstone *et al* 2017). At the same time, large, inflexible, centralized, monodirectional and supply-focused market structures dominated by legacy infrastructures, technologies and supply chains are being challenged by an increasing emphasis on facilitation and citizen involvement (Eyre and Lockwood 2016; Green Alliance 2017; Sandys *et al* 2018; World Energy Council 2017a).

Data availability, accumulation, management and analytics are often considered to be key determinants in the success of new energy system architecture (BEIS/Ofgem 2017; Mitchell 2017; Sandys *et al* 2018). Distributed ledger technologies (DLTs), such as blockchain, and emerging digital innovations, such as smart sensors, smart meters, the internet of things (IoT) and artificial intelligence (AI), are increasingly automating and digitizing measurement, reporting, verification and accounting infrastructures (World Bank 2018). Combined with executing smart contracts, such digital innovations ostensibly facilitate the deep learning required for more accurate time series predictions and the automation of peer-to-peer (P2P) trading, demand management, demand-side response (DSR), flexibility and carbon accounting (DAO–IPCI 2018; EnergiMine 2018; EWF 2018; Flexitricity 2018; World Bank 2018).

In the United Kingdom, as elsewhere, there is also an understanding that embedding digital innovations into, or overlaying them onto, existing energy systems is not sufficient to achieve long-term 4D objectives, because current energy governance has been designed around value creation from fossil-fuel generation and supply-focused markets as well as data security implications (Sandys *et al* 2018). A new fit-for-purpose system embedding the 4Ds will need to be more marketized, with all aspects of energy (non-)use being monitored, and capable of integrating a range of technological, economic and social innovations by prioritizing transparency, flexibility and a focus on people through regulatory reform (Mitchell 2017; Ofgem 2017a; Sandys *et al* 2018).

Rather than competitive efficiencies and paying per unit of generated electricity, new payment approaches are necessary to reward flexibility, DSR, demand reductions and the accumulation of measured, reported, verified and certified carbon emission mitigations (Green Alliance 2017; Ofgem 2017a; Sandys *et al* 2018; Stua 2017). Progressive energy market governance is thus essential for this redirection of markets to derive value from decarbonized, decentralized and digitized outcomes while ensuring meaningful consent through democratization, especially regarding vulnerable members of society.

This paper provides an overview of the current situation, where energy governance comprising law, regulation and policy attempts to square grid code written for large-scale generators and wholesale traders with the challenges of the 4Ds. This implies an increasing emphasis on facilitating smart, flexible and distributed systems along with digital innovations, while dealing with an overall retreat of interventionist capabilities that is providing decentralized actors with an increasing range of opportunities. By conceptualizing digital innovations as transactional technologies, this paper analyzes the transaction costs of governance arrangements of dis- and re-intermediation associated with innovative decentralized renewable energy, flexibility and energy services as well as a shift in the source and understanding of value.

This paper seeks to answer the following questions.

- How do digital innovations challenge the governance of decentralized renewable energy, flexibility and energy services?
- What is the role of UK energy law, regulation and policy in facilitating digital innovations?
- Do digital innovations change the process of value creation in energy systems?

In answering these questions, the paper uses a social science approach that combines a literature review, participant observations and interviews. The literature review provides an empirical basis on which to analyze the impact of digital innovation on UK energy governance and value creation in energy systems more broadly, and to establish the conceptual framework for transaction cost analysis. Participant observation and note-taking at conferences, such as Event Horizon 2018 in Berlin and Blockchain Live in London, as well as closed meetings, where specifics of digital innovation implementation and energy governance implication were discussed, have complemented the development of an empirical basis for analysis. Supplementary informal and formal interviews have provided details on opportunities and shortfalls to help develop a deeper understanding of the implications of digital innovation diffusion on energy governance.

This paper is structured as follows. Section 2 provides background information of UK energy governance. Section 3 introduces the key digital innovations that are affecting energy market governance. Section 4 introduces the conceptual framework of UK energy market governance and the analytical framework thereof, based on transaction cost economics. Section 5 analyzes the governance of decentralized renewable energy, flexibility and energy services in light of digital innovations. Section 6 discusses the effects of digital innovations on UK energy governance and associated value creation. Section 7 concludes.

2 UK ENERGY GOVERNANCE

Energy law in the UK concerns

> the management of energy resources and the rights and duties over all energy activities over each stage of [the] energy life cycle and at the local, national and international level. This includes all of primary and secondary energy, renewable and non-renewable energy and conventional and unconventional energy.
>
> Heffron *et al* (2016)

Energy in the United Kingdom is regulated through acts such as the Electricity Act 1989, the Energy Act 2004 and the Energy Act 2013 (DECC 2011; Eyre and Lockwood 2016).

The UK's overarching energy policy objectives are affordability, energy security and sustainability (Sandys *et al* 2018). These objectives are underpinned by regulatory instruments, economic instruments and fiscal/financial instruments that play different roles in energy markets (IEA 2018). Regulatory instruments are often reactive in ironing out issues that arise in the market. Economic and fiscal instruments such as feed-in tariffs and contracts for difference are often proactive through the implementation of political promises and comparatively easy to both enforce and end (House of Commons 2016; IEA 2018).

UK energy policy relating to these economic and fiscal instruments is often perceived as erratic and unpredictable due to sudden changes reducing or removing support, especially in renewable energy projects (Ernst and Young 2015; House of Commons 2016). UK energy regulation, however, is perceived globally as leading on regulatory reform (Sandys *et al* 2018). This can be traced back to liberalization reforms in the 1980s and 1990s, which saw the United Kingdom's heavily regulated supply market replaced by a competitive supply market through the privatization of electricity and transmissions networks as well as the subsequent imposition of more direct regulatory instruments on supposedly free-market structures in the 2000s, following their failure to deliver optimum outcomes to consumers and the environment (Eyre and Lockwood 2016; Mitchell 2008; Pollitt 2010; Sandys *et al* 2018).

Carbon pricing was introduced in 2002 by the Department for Environment, Food and Rural Affairs (DEFRA) in response to the EU Emissions Trading System, while EU regulations such as Directive 2009/28/EC are credited with ambitious renewable energy targets. Both, however, are outside of the framework of UK energy market regulation (Eyre and Lockwood 2016; House of Commons 2018; Mitchell 2008; Pollitt 2010). Recent changes in energy market regulation such as the United Kingdom's Electricity Market Reform in the 2013 Energy Act have taken into account an increasingly diverse range of supply technologies (Eyre and Lockwood 2016).

The latest EU Renewable Energy Directive (EU 2016a) and the 4th EU Electricity Directive (under review: see Eyre and Lockwood (2016)) take this a step further by providing more rights to individual and collective consumption, facilitated by the increasing prevalence of decentralized and decarbonized generation technologies (Eyre and Lockwood 2016, Article 21):

> Member States shall ensure that renewable self-consumers, individually or through aggregators, are entitled to: (a) generate renewable energy, including for their own consumption, store and sell their excess production of renewable electricity, including through power purchase agreements, electricity suppliers and P2P trading arrangements.

Actual implementation is the responsibility of the Office of Gas and Electricity Markets (Ofgem), which acknowledges that "moving from a largely centralised, carbon-intensive model to one which will be increasingly carbon-constrained, smart, flexible and decentralised is creating challenges which can only be addressed by innovation" (Ofgem 2016). To this end, it has been collaborating more and more with the UK Department for Business, Energy and Industrial Strategy (BEIS), especially in the context of the security of network and information systems (BEIS/Ofgem 2017).

The result is that Ofgem and BEIS, along with individual district network operators (DNOs), are in the process of setting rules for smart and flexible energy systems in light of energy system transformation and digital innovations (BEIS/Ofgem 2017; Sandys *et al* 2018). There is an expectation that these new rules will address the regulatory gap which fails to empower citizens as "prosumers" due to a lack of clarity regarding the role of the individual in energy system transformation (Saintier 2017). They should also help to mitigate the gap between current energy policy and requirements for meeting the United Kingdom's fourth and fifth carbon budgets (CCC 2018). Table 1, which is taken from Mitchell (2018), indicates the Committee on Climate Change's expected progress indicators.

TABLE 1 Committee on Climate Change's expected progress indicators (Mitchell 2018).

	2017/18	2030
Low carbon generation as share of total	52%	>75%
ULEVs as share of new cars	<2.5%	60%
Heat pumps in homes	<200 000	2.5 million
Electrical storage	2.7 GW	8–38 GW
DSR	1 GW	4–18 GW
Carbon intensity of electricity generation	265 gCO_2/kWh	<100 gCO_2/kWh

ULEVs are ultra low emission vehicles.

Despite this increasing emphasis on regulatory reform in the United Kingdom, a misalignment between policy-induced innovation and regulatory instruments persists (Hoppe *et al* 2018; Saintier 2017). The result is that missing market rules and high entry barriers are encouraging innovators and prosumers to push regulatory limits or to seek/provide alternatives through grid and regulatory defection.

3 DISTRIBUTED LEDGER TECHNOLOGY, EMERGING DIGITAL TECHNOLOGY AND BIG DATA ANALYTICS

As mentioned above, access to data is one of the key determinants in the development of smart, flexible and low-carbon energy systems (BEIS/Ofgem 2017; Mitchell 2017; Sandys *et al* 2018). Data availability, accumulation, management and analytics will be greatly enhanced through digitalization, which encompasses the growing application of information and communication technologies (ICT) across energy systems (IEA 2017). In the context of this paper, digitalization also includes DLTs, such as blockchain, and emerging digital technologies (EDTs), such as the IoT and AI (IEA 2017; World Bank 2018). Despite increasing awareness of the importance of data, DLT and EDT, there is still significant uncertainty regarding the extent of their application and impact.

3.1 Distributed ledger technology

DLTs and blockchain in particular have been touted as a potential catalyst for change in a variety of markets, ranging from energy markets to climate markets (PwC 2016; World Bank 2018; World Energy Council 2017b, 2018). As transactional technologies, DLTs facilitate market transactions and enhance connectivity by lowering transaction costs (Davidson *et al* 2016). Applications of DLT in the energy sector include grid management, certificate-of-origin trading, payment systems associated with renewable energy and electric vehicle charging, and energy asset management, especially where the "provenance of an asset and the data from it [need] to be interrogated and updated by multiple parities" (World Energy Council 2017a, p. 4).

3.2 Emerging digital technology

EDTs at the intersection of digitalization and energy include smart sensors, smart meters, smart inverters, frequency relays and active dispatch capabilities, which are often grouped together as elements of the IoT as well as AI. EDTs promise highly integrated, interconnected and responsive energy systems. Analysis by the International Energy Agency suggests that the curtailment of wind and solar photovoltaics (PV) can be reduced from 7% to 1.6% by 2040 with the help of EDTs (IEA 2017). Flexibility, efficiency and reliability can thus be increased through the exchange of operational information in real time between any interconnected equipment anywhere in the energy system (IEA 2017).

3.3 Big data analytics

Big data analytics (BDA) of data provided by EDTs enables real-time (non-)usage monitoring and prediction of early-stage problems, even before mechanical failure interrupts operations. This can help reduce operation and maintenance (O&M) costs, improve network efficiency, reduce unplanned outages and downtime, and extend the operational lifetime of assets. Given the exponential growth in data, AI will play an increasingly important role in managing data (IEA 2017).

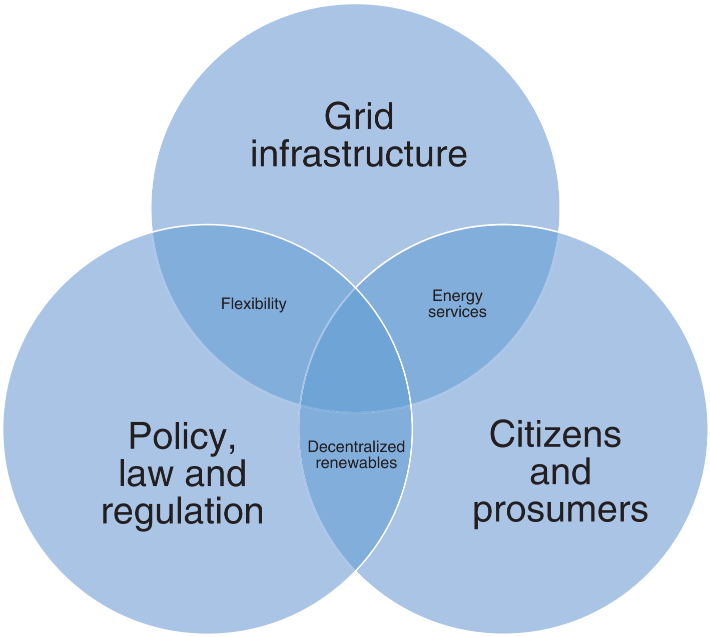
4 CONCEPTUAL FRAMEWORK

The digital innovations described in Section 3 are understood as transactional technologies in this paper, and the energy system they support may be described as transactive energy, defined by Liu *et al* (2017) as

> a system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter.

To promote the "convergence of technologies, policies and financial drives in an active prosumer market where prosumers are buildings, EVs, microgrids, VPPs or other assets" (Liu *et al* 2017) and the desire to remove barriers to realizing the value of smart digital technologies (BEIS/Ofgem 2017) does not exclude the democratic element of the 4Ds, this paper provides the following simplified analytical framework of the United Kingdom's current energy system governance (Figure 1).

FIGURE 1 UK energy system governance (own impression).



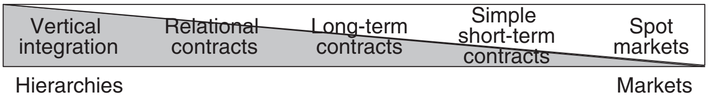
This analytical framework locates decentralized renewable energy at the intersection of policy/law/regulation and citizens and prosumers; flexibility at the intersection of grid infrastructure and policy/law/regulation; and energy services at the intersection of grid infrastructure and citizens and prosumers.

The emergence of associated markets is driven by interactions between governance, which provides market frameworks, and innovators, who reduce transaction costs by opening new markets and reorganizing industry (Anderson and Parker 2013; Schumpeter 1934). This analytical framework provides the basis for analyzing the transaction costs of dis- and re-intermediation associated with the interactions between digital innovations and innovative decentralized renewable energy, flexibility and energy service market governance arrangements.

The analysis of transaction costs can be traced back to Coase (1937), who stated that firms exist because of the transaction costs of using the markets. Transaction costs are the costs incurred

> to discover who it is one wishes to deal with, to inform people that one wishes to deal and on what terms, to conduct negotiations leading to a bargain, to draw up

FIGURE 2 Spectrum of governance structures (adapted from Pint and Baldwin (1997)).



> the contract, to undertake the inspection needed to make sure that the terms of the contract are being observed, and so on.
>
> Coase (1960, p. 15)

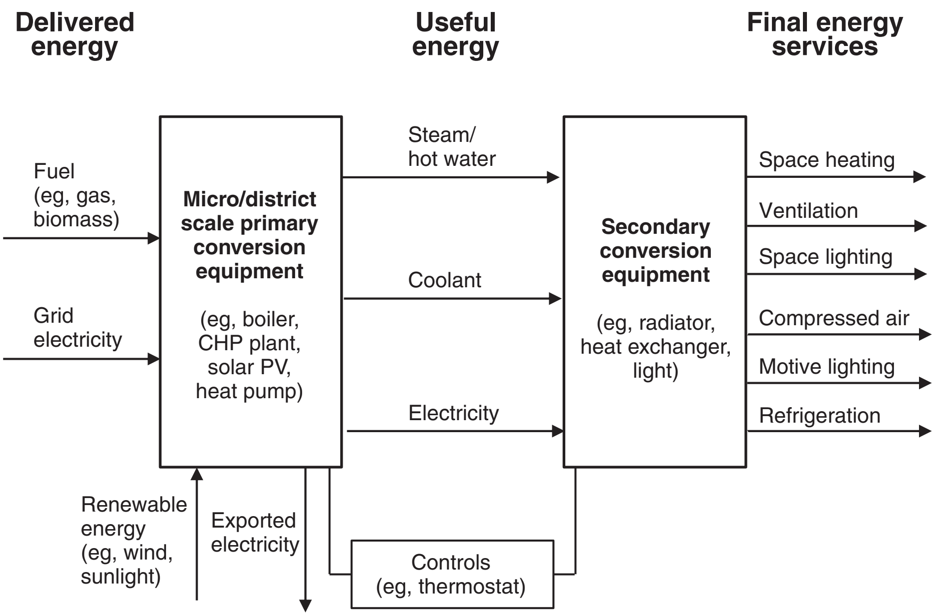
The mix of economic institutions for economic coordination is therefore determined by agents seeking to economize on transaction costs. Uncertainty (bounded rationality) leads to contractual incompleteness. Williamson (1985) developed this theory further by stating that hierarchical organizations (firms, left-hand side of Figure 2) reduce opportunism and are considered more transaction cost-efficient than markets (right-hand side of Figure 2). Organizational form is largely shaped by the need to control opportunism (the lack of trust). Therefore, governance exists to counter the risk of opportunism (Davidson *et al* 2016; Williamson 1985).

According to this view, transactions are governed through structures located on a spectrum with hierarchical organization (firms) at one end and spot markets at the other (see Figure 2 (Pint and Baldwin 1997; Toffel 2002)).

While hierarchical organizations have lower transaction costs for vertically integrated contracts (left-hand side of Figure 2), markets are often more efficient governance institutions for spot contracts (right-hand side of Figure 2) (Williamson 1985). In a pure exchange economy, all contracts would be spot contracts. Economic activity that requires coordinated investment over time (asset specificity and associated opportunism) along with management of uncertainty and frequency of dealings, however, benefits from hierarchies and relational contracting (left-hand side of Figure 2) because they provide more efficient ways to deal with the hazards of opportunism. Because associated transactions are more efficiently conducted in hierarchies than markets, transaction costs determine the efficiency of different governance institutions (Davidson *et al* 2016).

The inflexible and centralized legacy grid has traditionally monodirectionally supplied electricity from utilities to customer's sites (left-hand side of Figure 3). With the diffusion of decentralized generation technology (such as solar PV) and changing business models (such as energy service companies), our dependency on utilities to deliver grid electricity (and fuel) is diminishing in favor of the supply of useful energy provided by primary conversion equipment on-site or adjacent to the customer (center-left of Figure 3).

FIGURE 3 Delivered energy, useful energy and energy services on-site (Hannon and Bolton 2015; Nolden and Sorrell 2016; Sorrell 2007).



DLT, EDT and BDA are providing new openings and opportunities to govern decentralized renewable energy, flexibility and energy services as well as secondary market access. Governance structures are thus more likely to resemble markets. The transaction costs for accessing such markets have traditionally been high for individual organizations, who are likely to prioritize their core business, and insurmountable for citizens and prosumers. Innovative energy service companies (ESCOs) are increasingly providing access to such markets through technology specialization and the application of DLT, EDT and BDA as transactional technologies. Rather than conventional asset-based business models (top of Figure 1), these ESCOs seek to provide asset-free platform business models capable of capturing monopoly rents.

5 CHANGING RETAIL ENERGY MARKETS

Decentralized renewable energy generation technologies lower transaction costs for consumers to source an increasing share of electricity generation in-house (left-hand side of Figure 2). This reduces their dependency on grid electricity and conventional organizational structures such as utilities (left-hand side of Figure 3). Digital innovation combined with changing business models lowers transaction costs for innovative ESCOs to provide flexibility, DSR and demand management services. Both trends imply a change in the way the energy system is organized. The following section analyzes how changes in decentralized renewable energy, flexibility and energy services require a reassessment of UK energy system governance at both the citizen and prosumer (bottom of Figure 1) and the policy/law/regulation levels (left-hand side of Figure 1).

5.1 The governance of decentralized renewable energy

To date, the difficulty of managing electricity at the individual and household levels (bottom of Figure 1) has implied that grid electricity regulated by Ofgem and supplied by utilities remains the primary source of electricity (left-hand side of Figure 3). At the same time, an increasing share of on-site generation supplements grid supply, with exports deemed at a certain percentage of generation (bottom-left of Figure 3). With the increasing availability of primary conversion equipment for electricity at a diverse range of sites, the shift from a monodirectional supply of electricity from the grid toward a bidirectional flow of electricity is underway (Green Alliance 2017; Ofgem 2017a; Parag and Sovacool 2016; Sandys *et al* 2018).

The growing cost-effectiveness of solar-PV-plus-battery reinforces this trend by increasing opportunities for on-site prosumption and managed grid exports (DECC 2015; Ofgem 2017a; REA 2016). With digital innovations supporting nano- and microgrid experimentation and facilitating P2P electricity trading, further opportunities for prosumption and supply at a local level are arising (Zhang *et al* 2017, 2018). Decreasing transaction rates provided by such digital innovations thus transform the governance of decentralized renewable energy by enabling individuals and communities to transact small amounts of energy in such microgrids.

Compared with electricity trading through public grid infrastructures, private wire supply through microgrids requires the installation of dedicated physical electricity transmission infrastructure. These arrangements are complex, requiring considerable skills and the capacity to engage with appropriate network design, infrastructure, installation costs, land and planning requirements, and operation and maintenance, thus increasing both transaction and production costs (Sorrell 2007; Stephens Scown/Regen SW 2016). Easton Energy Group in Bristol, for example, is at the forefront of developing a community microgrid combining solar PV generation with battery storage and dedicated transmission infrastructure as part of their TWOs project (Regen/10:10 Climate Action 2018).

The cost-effectiveness of such microgrid arrangements, however, remains doubtful. A more diffusible approach seems to be platform organizations facilitating direct connections between producers and consumers, with the aim of transforming current grid infrastructures through decentralized and trustless P2P or platform trading. On April 12, 2018, the first ever electricity trade on the blockchain took place in the United Kingdom by combining solar PV with battery storage and digital technologies provided by Verv in Hackney Banister House Estate (Verv 2018). The current understanding appears to be that production cost savings only accrue to individuals and communities engaging in such trades, with network charges and auxiliary costs being socialized. A progressive view sees these actors as decentralized flexibility providers in a more integrated energy system enabled by digital innovations (Sandys *et al* 2018, p. 8):

> Renewable energy is no longer marginal, but mainstream; distributed electricity generators, balancers and system service providers are multiplying; and non-energy players in the technology and data sectors now view energy as an exciting new market. Consumers will be the key drives acting as the crucial market makers rather than market takers of today. As connected consumers, they are likely to be serviced by new big data companies, demanding a new set of optimized outcomes that will throw up new issues around the definition of security of supply, such as cyber security.

An emerging issue appears to be the need to enhance consumer, prosumer and citizen awareness of the changing regulatory environment in light of rapid technological advances lowering transaction costs across this increasingly transactive energy system. The disintermediation of established market players appears to be a likely consequence, to allow for the transaction of fairly small amounts of energy at very local scales (shifting from the center of Figure 2 toward the right of Figure 2). In addition, some form of reintermediation might be necessary to aggregate such transactions to benefit the grid for engagement in flexibility services and to automate the accounting of carbon emission mitigations.

5.2 The governance of flexibility

This reintermediation process describes a parallel trend of increasing on-site generation, customer and/or community-owned primary and secondary conversion equipment, and a growing number and variety of ESCOs specializing in the development of trading platforms for such flexibility services, such as Upside Energy, Flexitricity, Limejump, Origami Energy and KiWi Power. These ESCOs take an asset-light, data-driven approach to flexibility service delivery by using existing infrastructure to provide demand-side and frequency response services, which are expected to deliver benefits in the range of £17–40 billion to 2050 (Sanders *et al* 2016).

These complex management arrangements, involving a range of digital innovations, combine spot market contracts (right-hand side of Figure 2) with more static long-term (2–4-year) contracts for flexibility service delivery in the future (center of Figure 2). These long-term energy service contracts only make sense if the sum of the production costs of accessing such secondary markets as well as the transaction costs associated with governing their provision are lower than the in-house provision (left-hand side of Figure 1).

Citizens, prosumers and small businesses are excluded from these markets due to the high transaction costs of engaging with their small electricity loads. A 100 kW threshold at the DNO level requires aggregation, but few ESCOs and other intermediaries appear to be ready to take on this challenge. At the same time, first-moving ESCOs that succeed in reducing transaction costs and providing secondary market access play an important role in establishing precedents and providing those responsible for energy system governance with a clearer idea of how these emerging markets function and how they need to be regulated.

To enable maximum flexibility, the bidirectional flow of data relies on a combination of storage, DSRs, interconnection and energy efficiency, which benefit from enabling smart and digital innovations to reduce transaction costs (Pop *et al* 2018). This points toward the emergence of paradoxical systems, where spot markets determine the trade of electricity (right-hand side of Figure 1) while the systems themselves more closely resemble vertically integrated governance platforms (left-hand side of Figure 1). Facilitated by DLT and blockchain in particular, these intermediary platforms arguably provide the basis for establishing entirely new rule-governed economic orders outside the traditional spectrum of governance structures between hierarchies and markets (Davidson *et al* 2016; Pint and Baldwin 1997; Toffel 2002).

The full potential of digital innovations therefore lies in bypassing both hierarchies (such as utilities delivering electricity) and established markets (such as the electricity market regulated by Ofgem) by creating "institutional alternatives for coordinating the economic actions of groups of people" (Davidson *et al* 2016, p. 18). Yet, the regulator still needs to keep an open mind about the possibilities and limitations of both established and emerging technologies in future energy systems.

5.3 The governance of energy services

The governance of energy services, alongside advances in electricity generation and storage technologies, flexibility and demand-side and frequency response services, is also undergoing significant changes. If interoperable management capabilities were to be rolled out at highly diverse scales, a reconceptualization of the grid and energy service delivery in general might be necessary, as each component and each boundary area scale, ranging from device via building to substation, ends up being a self-contained ecosystem capable of providing services to the next layer in the system (Bronski *et al* 2017).

Rather than self-contained microgrids, as in the case of Easton, such an infrastructure would require interoperability driven by the hierarchy of grid voltages.

This might imply a shift from spot (real-time) markets (right-hand side of Figure 2) and futures (days to years ahead) markets toward automated responses with ex-post settlements based on buying and selling transactional records (Bronski *et al* 2017). The Energy Web Foundation has developed a blockchain-based transactive energy implementation framework called the decentralized autonomous area agent (D3A) market model; this enables all grid services to be provided from the bottom up by a transactive energy service market capable of scaling to any level within the grid and embedding decentralization, decarbonization and digitization. By increasing choice, improving access and enabling participation, it might also contribute to democratization (Bronski *et al* 2017).

Similar to this bottom-up approach to the delivery of energy services and the development of a transactive market model, Sandys *et al* (2018) apply a backcasting methodology to envision future energy market regulation from the socket upwards. They foresee a transformation of energy service delivery into a "technicolour range of opportunities and consumer propositions" (Sandys *et al* 2018). The success of this vision, however, hinges on the interplay of energy market governance, ESCOs and digital innovations to lower transaction costs for their delivery.

One increasingly prevalent argument in the context of lowering transaction costs is to do with value (see Section 4). Delivering energy services such as flexibility has multiple social and economic values that change according to network, social and environmental context (Shipworth 2018) as well as space and time (Atkinson *et al* 2018). BEIS/Ofgem (2017) call for the stacking of such values across existing markets (capacity, wholesale, balancing and ancillary services) and emerging markets (at distribution level and for new services).

Digital innovators, however, suggest that value assigned to resilience, customer choice, environmental outcomes and customer equity should play an increasingly important role (Pop *et al* 2018). This is also echoed by those calling for regulatory reform in the shape of a less unit-price-sensitive value proposition that delivers wider service benefits to the consumer while placing decarbonization at the heart of the energy service system (Sandys *et al* 2018).

6 DISCUSSION

Digital innovations pose a challenge to energy system governance. Such innovations, alongside advances in multiscalar energy generation and storage technologies as well as business model innovation in energy and flexibility service provision, are driving both the decentralization and the decarbonization of the energy system. Their governance requires collective governance as an interlinked, interconnected and interoperable community, which stands in contrast to existing energy governance structures.

Law, regulation and policy are no longer in control of the energy system originally designed around these supply-focused markets. Accountability is increasingly located within networks, with law, regulation and policy taking on a facilitatory role in the development of smart and flexible systems. The United Kingdom is not alone in its struggle to engage and integrate a range of technological, economic and social innovations promising consumer-oriented solutions to environmental problems. Yet, the United Kingdom's position – supposedly at the forefront of energy regulation (Sandys *et al* 2018) – stands in contrast to its inherent policy bias toward incumbent systems, especially in relation to nuclear power (Johnstone *et al* 2017).

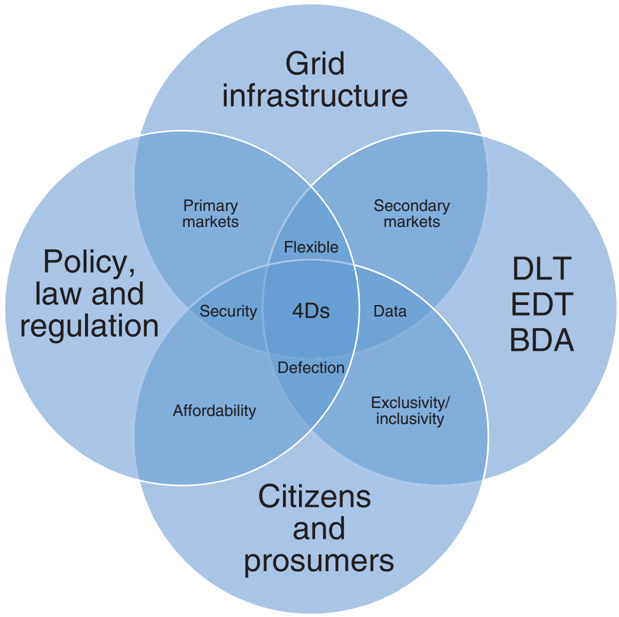
In practice, however, the rapid diffusion of multiscalar generation and storage technology as well as digital innovations is already disrupting market structures. The automation of digital accounting and measuring, reporting and verification infrastructures, as well as the execution of smart contracts, is set to facilitate the deep learning required for more accurate time series predictions; this lowers the risk of opportunism, but questions arise regarding the role of the citizen both as a "prosumer" and an energy data provider. This entails a process of disintermediation, whereby suppliers alongside law, regulation and policy play a decreasing role while innovative ESCOs, platform providers, communities and prosumers appear to be in the process of reintermediation from the bottom up.

The result is an energy system in which digital innovations play a greater role even though the extent and pace of change is unknown. In relation to the 4Ds of decentralization, decarbonization, digitalization and democratization (Figure 1), UK energy governance increasingly locates

- decentralized renewable energy at the intersection of policy/law/regulation, DLT/EDT/BDA and citizens and prosumers, which currently fails to discourage grid and regulatory defection;
- flexibility at the intersection of grid infrastructure, DLT/EDT/BDA and policy/law/regulation, even though citizens and prosumers will need to be engaged because flexibility markets engaging "large players" only reach about 30% of the energy load on the grid; and
- energy services at the intersection of grid infrastructure, DLT/EDT/BDA and citizens and prosumers, largely in an unregulated space from an energy governance perspective.

Whether the vision of digital innovators will be fulfilled, however, remains to be seen. This is linked to the difficulty of (re-)locating value within energy system transformation. Value creation needs to shift from fossil-fuel generation and supply-focused markets toward progressive energy market governance. Value needs

FIGURE 4 UK energy system governance and the 4Ds (own impression).



to be sourced from decarbonized, decentralized and digitized outcomes and based on meaningful consent through democratization, especially regarding vulnerable members of society.

Fairness and equity therefore need to be prioritized through a process of democratic, bottom-up citizen and community engagement to ensure that the costs of running the existing infrastructure (top of Figure 4, which will still be necessary no matter how rapidly distributed systems evolve) will not be borne by fewer and less fortunate consumers who lack the capacity to engage in these digital innovations (right-hand side of Figure 4). Therefore, new governance approaches are required to ensure that clean and flexible energy services will be available to all and created by all at affordable costs.

This challenge is reflected by Ofgem's dilemma of "whether it is financially beneficial for network users to install their own on-site generation or storage in order to reduce residual charges" while "facilitating effective decarbonisation of the energy system at the lowest cost to all consumers but possibly also around innovation or sustainable development" (Ofgem 2017b). At the same time, the power of top-down governance in energy system transformation should not be underestimated, despite the abovementioned shift toward collective energy system governance with an increasing emphasis being placed on private and community actors (Hoppe *et al* 2018; Saintier 2017).

For example, regulatory energy efficiency instruments in the United Kingdom are estimated to have had a larger effect historically than economic fiscal/financial energy efficiency instruments (DECC 2014; Eyre and Lockwood 2016). The consequences of regulatory decentralization and defection, after all, do not necessitate socially or environmentally beneficial outcomes. The more energy is governed outside of the scope of energy law, regulation and policy, the less effect changes in regulation will have in alleviating overarching issues such as climate change and inequality. This goes hand in hand with an overall loss of democratic accountability.

A culture change among regulators, standards developers and policy makers is required to balance established interests and legacy systems that "keep the lights on" by providing adequate services to those unable to adapt to the emergence of P2P and platform trading. Part of this culture of change might entail a greater understanding of the current trend toward exploiting latent flexibility, demand management and DSR capacities inherent in existing infrastructures.

7 CONCLUSION

It is evident that the United Kingdom's energy governance framework will need to change to enable energy system transformation toward the 4Ds. Digital innovations are enabling progress in some aspects, such as flexibility and demand-side and frequency responses, while potentially inhibiting progress in others, especially democratization, eg, by creating exclusive P2P trading environments.

The problem with energy system governance as it stands is that it is based on experience from the past. Regulating emerging technologies and facilitating beneficial outcomes while limiting potential negative ones requires a fine balance and technological agnosticism in "leveling" the playing field in favor of organizations that seek value creation beyond rent maximization. In this context, it is necessary to conceptualize decentralization and digitalization as value-free processes that can provide or limit opportunities for value creation through democratization (social value) and decarbonization (environmental value).

Those responsible for energy system governance need to proceed with caution and change law, regulation and policy in accordance with an understanding of decentralization and digitalization as vehicles that potentially, but do not necessarily, foster decarbonized and democratized outcomes. Facilitating change needs to be reflexive by taking a very wide range of statutory and nonstatutory requirements alongside long-term (decarbonization) targets into account.

In this context, it is necessary to bear in mind that it is not exclusively the responsibility of BEIS, Ofgem and DNOs to alter regulation. The National Grid and combined industry code panels governed by the Competition and Markets Authority and determined by the Secretary of State, as well as citizens and communities themselves, have a role to play. The drivers of change are also increasingly being found in carbon pricing and trading, which is the remit of DEFRA. Ultimately, carbon emission reductions and inequality need to be the main determinants of value creation in energy markets. Digital innovations provide the basis for data-driven accounting, which allows carbon emission reductions and inequality to be commoditized and automatically traded through (self-)regulated digital trading platforms. Democratization needs to ensure that accountability remains in the public sphere.

DECLARATION OF INTEREST

The author reports no conflicts of interest. The author alone is responsible for the content and writing of the paper.

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